NASA Center for Integrated Space Microsystems

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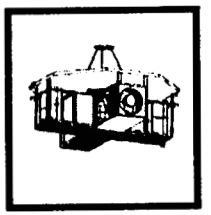
CISM
Avionics
Microelectronics
Miniaturization
Autonomy
Rapid prototyping
Deep Space Msns
Earth-orbiting
Missions

Outline

- Vision, Goals, and Objectives
- Scope
- Focused Research and Development Challenges:
  - X2000 Integrated Avionics
  - Towards an Avionics System on a Chip
  - Revolutionary Computing Architectures
- CISM Organization
- WBS
- Infrastructure Needs
- Facility Needs
- Summary

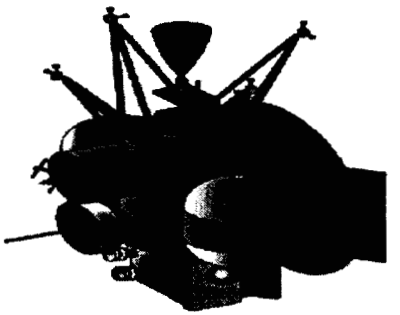
Vision:
Toward a Thinking Evolvable Spacecraft

"Thinking S/C"



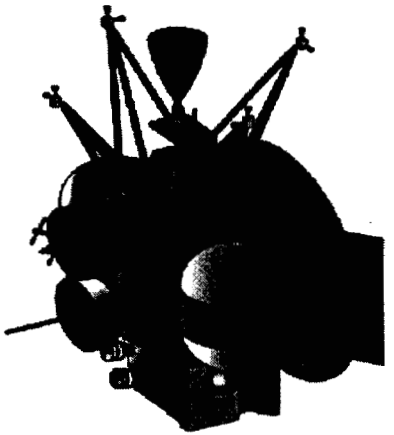
Evolvable HW
Upgradable SW

"X2000"



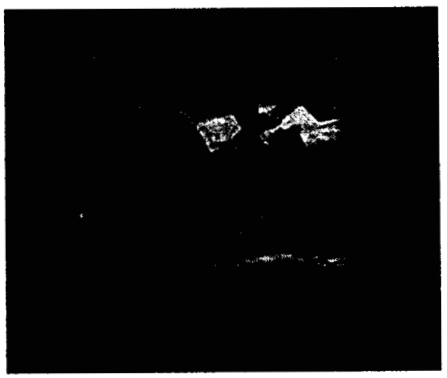
Reconfigurable HW
Upgradable SW

"Sciencecraft '96"

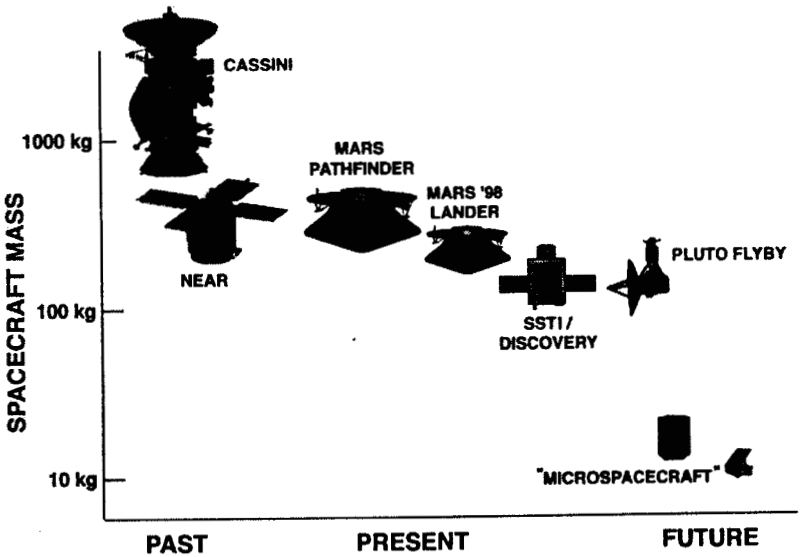


Fixed HW Design
Upgradable SW

"Galileo"



Fixed HW Design
Fixed SW Design



CISM Goals and Objectives

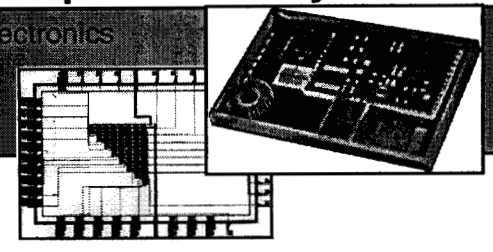
- Develop and maintain a world class, leading edge capability in Advanced Avionic Systems and Advanced Microelectronics Technologies for future highly integrated, miniaturized, autonomous spacecraft systems for deep-space and Earth orbiting missions.
- Establish and maintain a world class, leading edge facility for the design, development, rapid prototyping, and integration of highly capable autonomous microsystems that include:
  - Advanced Avionics Architectures and interfaces
  - Power Management and Distribution
  - Sensor Electronics and Focal Plane Arrays
  - Novel Computing Architectures and Technologies
- Establish and maintain world class program to research revolutionary computing architectures that will take us beyond the limits of semiconductor technology scaling, e.g.. quantum computing, holographic storage, optical communications, etc.

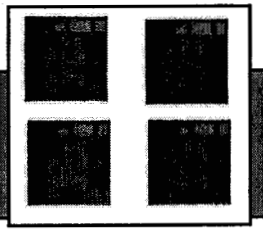
Advanced Deep-Space Spacecraft Program: CISM, X2000, & RPS

Technology Focus:

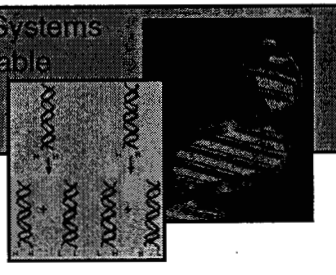
Integrated Space Microsystems

Low-Power Electronics
Autonomy
Data Systems

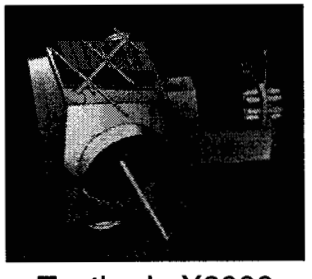




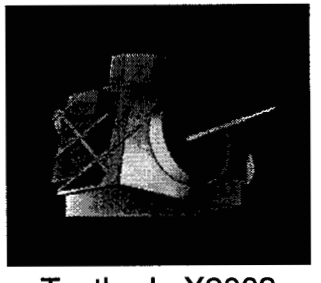
Evolvable Systems
Reconfigurable
Hardware



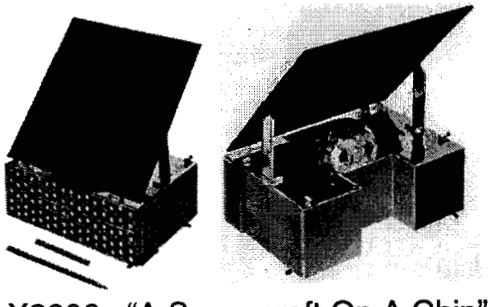
Novel
Computing
Concepts



Testbed: X2000



Testbed: X2003

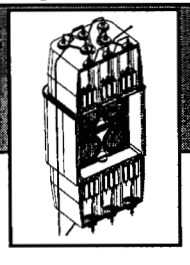


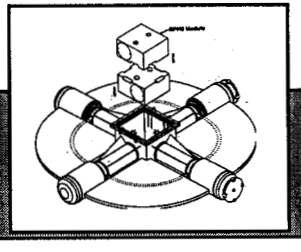
X2006: "A Spacecraft On A Chip"

Technology Focus:

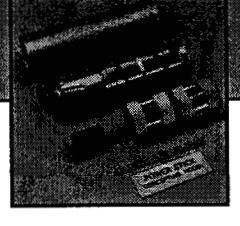
Advanced Power Systems

High-Efficiency Converters
"Bulletproof" Design
New Heat Source





Miniature Generators



Advanced
Power
Concepts

Supporting Technologies (Telecom, Propulsion, etc.)

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CISM Technology Focus
Assumes NASA funding at 15M$/year

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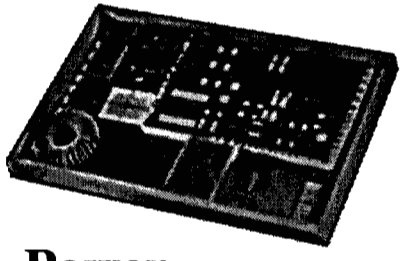
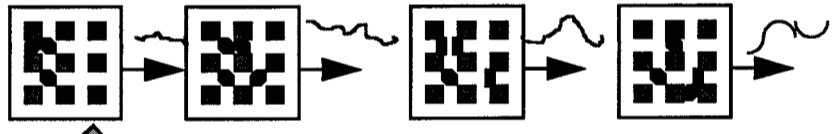


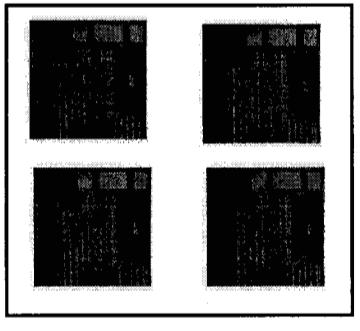
Data Systems, Power Electronics, and Communications

Evolvable Systems

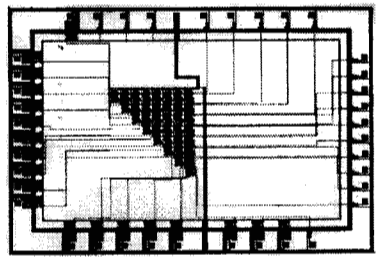


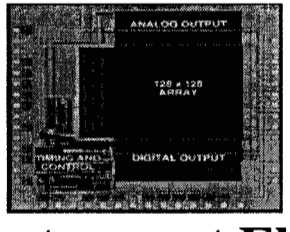
Ultra Low Power Technology

Rad Hard and Low Temperature



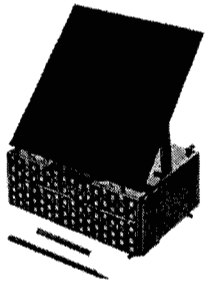
Programmable
Avionics on a chip

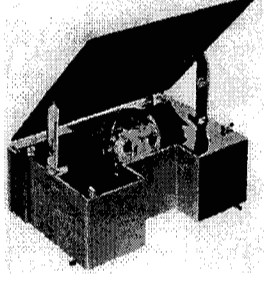




Instrument Electronics and Focal Planes

Advanced S/C Avionics Architecture

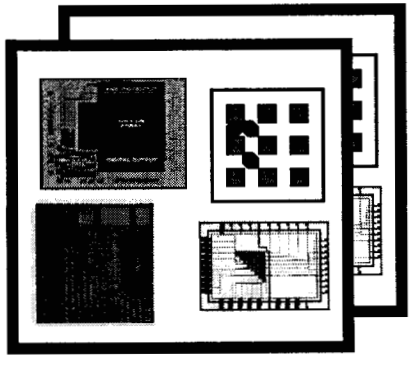


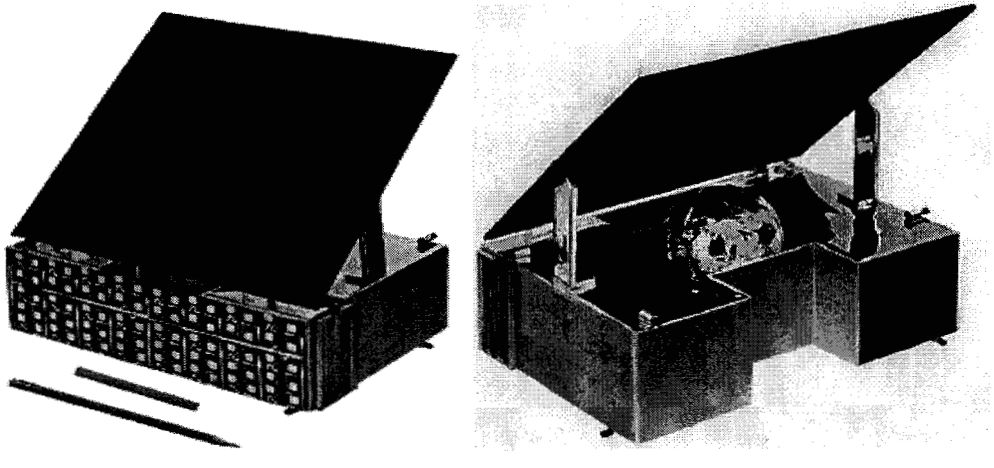


Novel Computing Architectures

CISM Scope

- CISM will be the focal point for the sytem architecture, core technology development, system level integration, and validation of breakthrough technologies for a complete Avionics on a chip that will integrate the computer, telecom, navigation, power management, and sensor technology into a single unit.



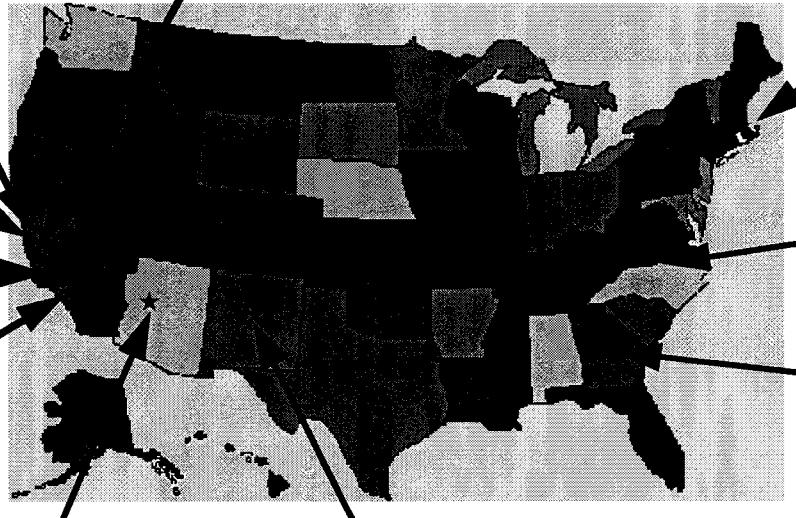


3-D Avionics System on a chip:

- **Data processing, storage, and I/O**
- **Power management and distribution**
- **Sensor technology, conditioning and processing**
- **Telecom (analog and digital)**

Second Generation Microspacecraft

CISM Partnerships



Stanford
CIS

BERKELEY
MEMS (NSF)

MIT/LL
Ultra Low Power
(DARPA)

Ames RC
(NASA)

NASA
Goddard Space
Flight Center

UCLA
MEMS (NSF)

Georgia IT
Packaging
(NSF)

JPL
(NASA)

U. Arizona
Low Power
(NSF)

U. New Mexico
Photonics, μElectronics
(NSF, NASA)

NASA/JPL Center of Excellence
Center for Integrated Space Microsystems (CISM)

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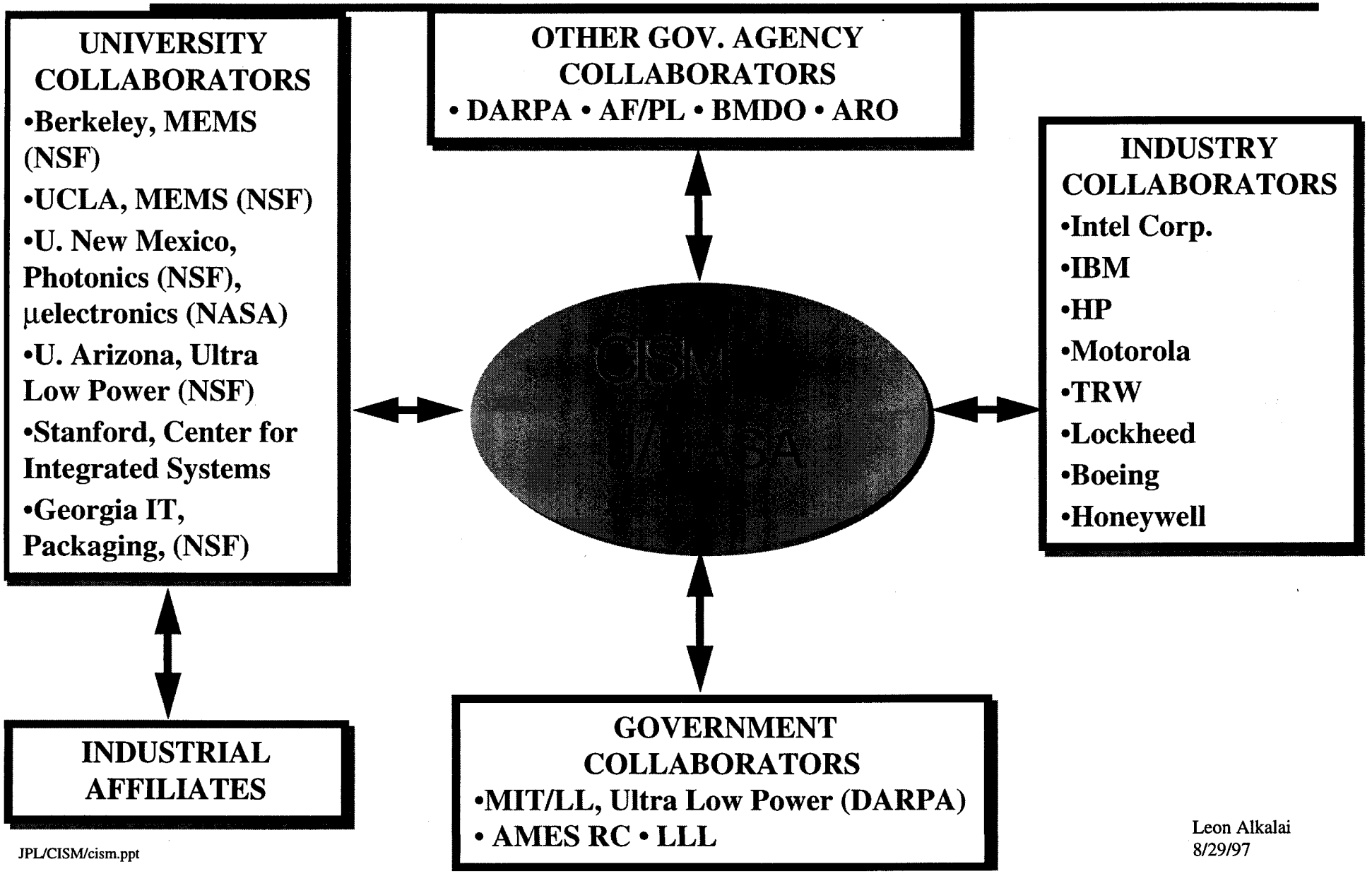

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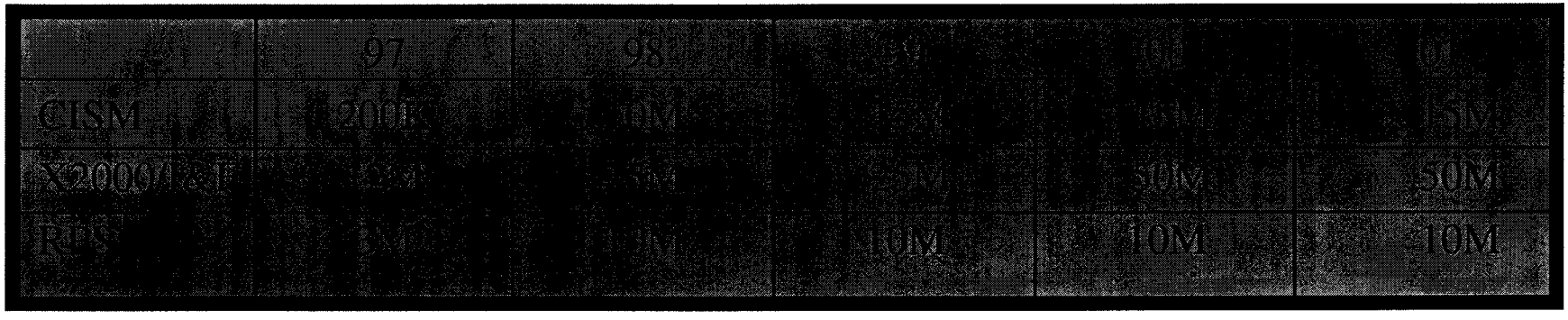
NASA Approved Funding Profile for the Deep Space Technology Development Program



	97	98	[illegible]	[illegible]	[illegible]
CISM	200[illegible]	[illegible]0M	[illegible]	[illegible]	15M
X2000/I&F	[illegible]	[illegible]	[illegible]	50M	50M
RPS	[illegible]	[illegible]	10M	10M	10M

Funding Assumptions:

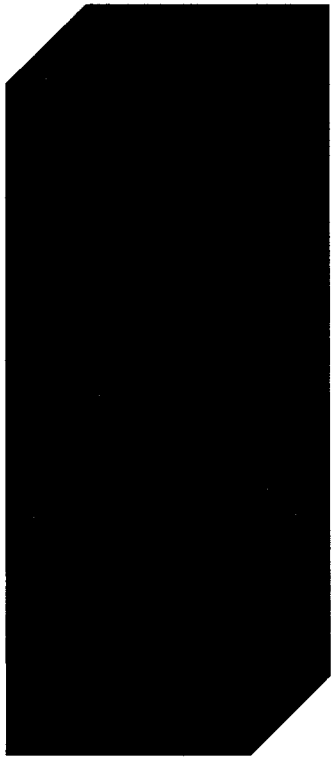
1) FY 97 funding for CISM, X2000, and Ice and Fire consist of reprogrammed 97 $.

2) CISM is being proposed as a JPL/NASA Center of Excellence, with additional JPL Technical Infrastructure support starting in FY 98.

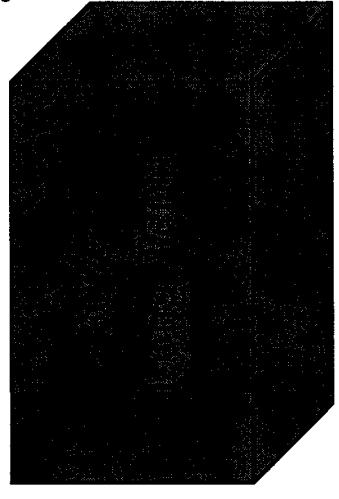
3) Additional funding for work to be performed under CISM is likely from other programs at DARPA, BMDO, DSWA, AF/PL, etc. A target of 20% of the CISM budget in 2001 is planned to be from non-NASA sponsors.

CISM Investment Strategy: A Balanced Portfolio

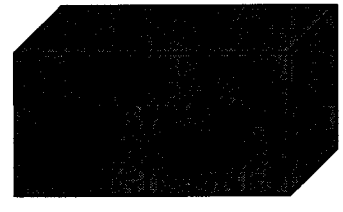
X2000 S/C
Electronics & Photonics



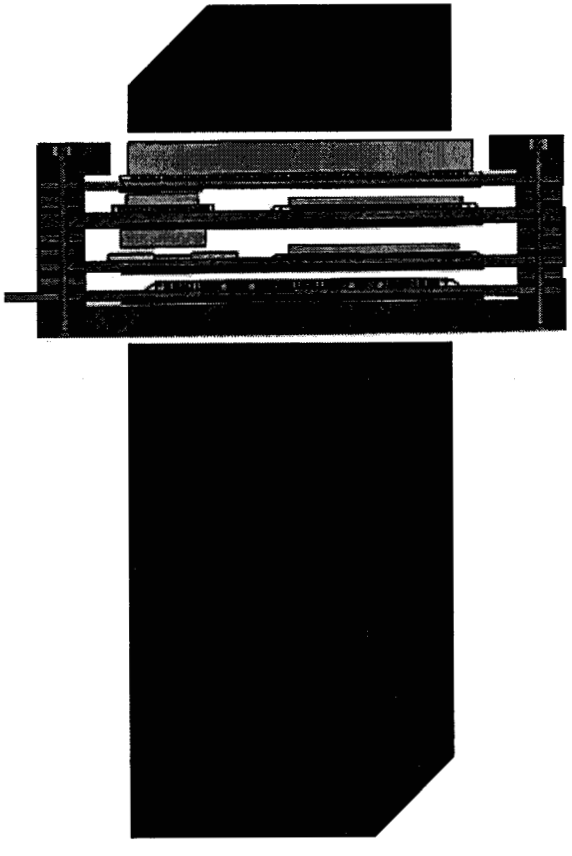
Towards an Avionics
System on a Chip



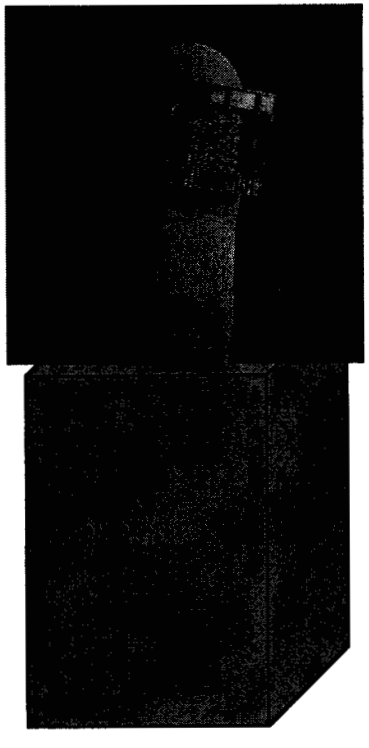
Revolutionary Computing
Architectures



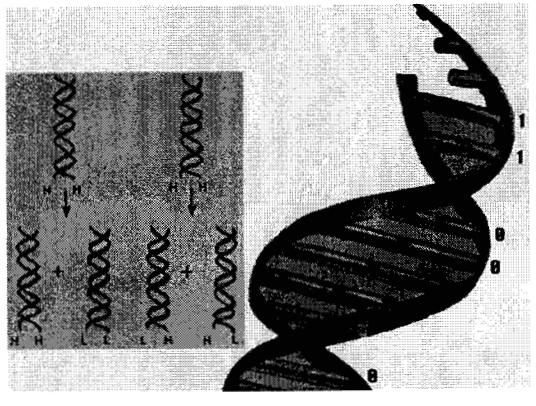
CISM Focused Technology Challenges



X2000 S/C Electronics
* Power Electronics
* Telecom processing
* 3D MCM standard
* Integrated Architecture



Avionics System on a Chip
* Start design and fabrication of minimum avionics system on a chip.
* Include Telecom, Power Management, CPU, Memory, and Sensors.



Alternative Computing
* Reconfigurable Computing
* Ultra Low Power Electronics
* Quantum Computing
* MEMS-Optics, etc.

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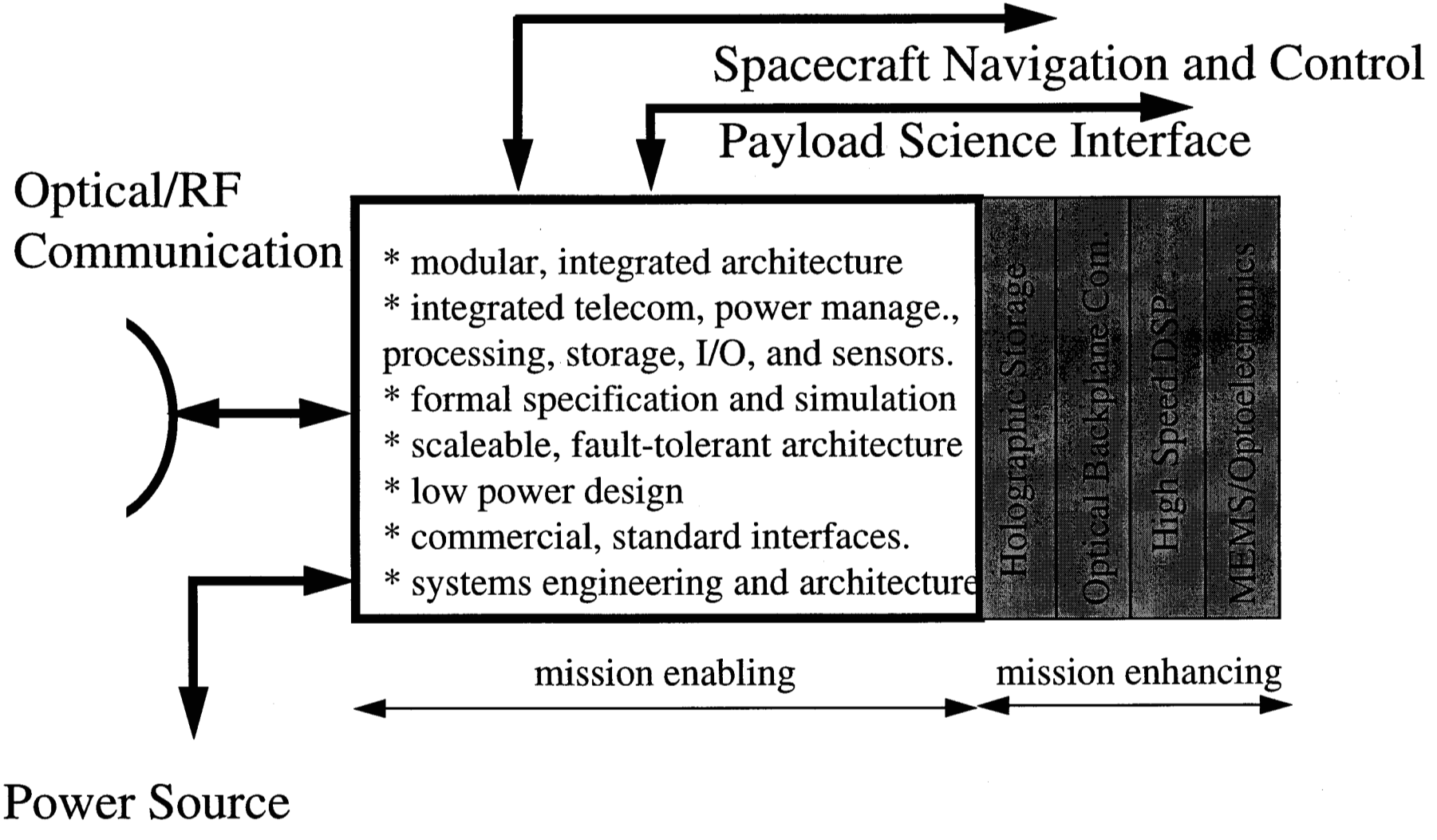
X2000 Integrated Avionics Challenge

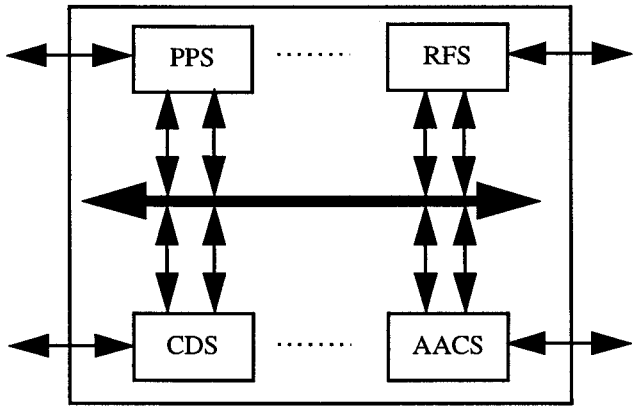
- Integrate ALL spacecraft electronics and opto-electronics: telecom, power management, data processing, storage, and sensors, into a single modular design.
- Develop an integrated 3D Microelectronics Systems industry standard.
- HW/SW Design for long-term survivability and fault tolerance.
- Develop Fault Tolerant Distributed Software architectures and techniques.
- Physics of Failure analysis and advanced Reliability Modeling.
- Design for low power architectures including reduced voltage levels, low activation rates, micro-power management, advanced microelectronics packaging, etc.
- Embedded intelligent sensors technology for radiation, temperature, current, voltage, stress, etc. sensing within the microelectronics system.
- High-Level Specification, Design, Simulation, Verification and Synthesis, using formal methods.
- Advanced Systems Engineering using design automation and integration tools; verify design before committing to hardware or software.
- Design for technology scaling: towards a system on a chip.

X2000 Integrated Microelectronics Challenge

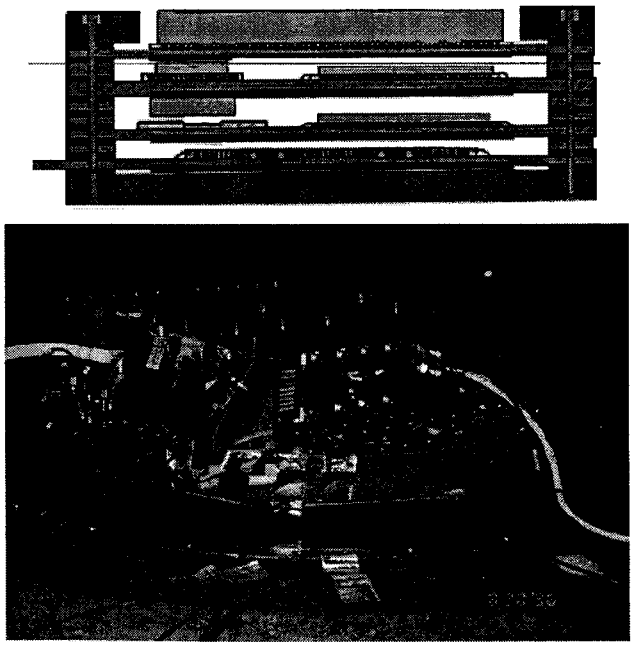


Design for Technology Scaling From Subsystems to Macro-Cells

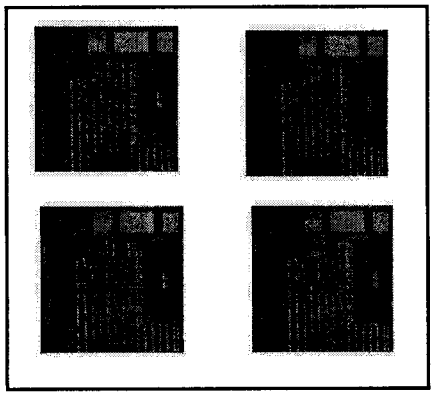
- All spacecraft electronic functions can be migrated to integrated circuits
- Spacecraft cabling is replaced by sub-micron metal/optical interconnects
- Spacecraft can "self-test" and autonomously adapt to faults and changing conditions
- CAD synthesis of highly integrated spacecraft "system"
- Concurrent developments in computer architectures and ultra-low power electronics



Traditional Sub-system Architecture



3-D Avionics MCM Stack

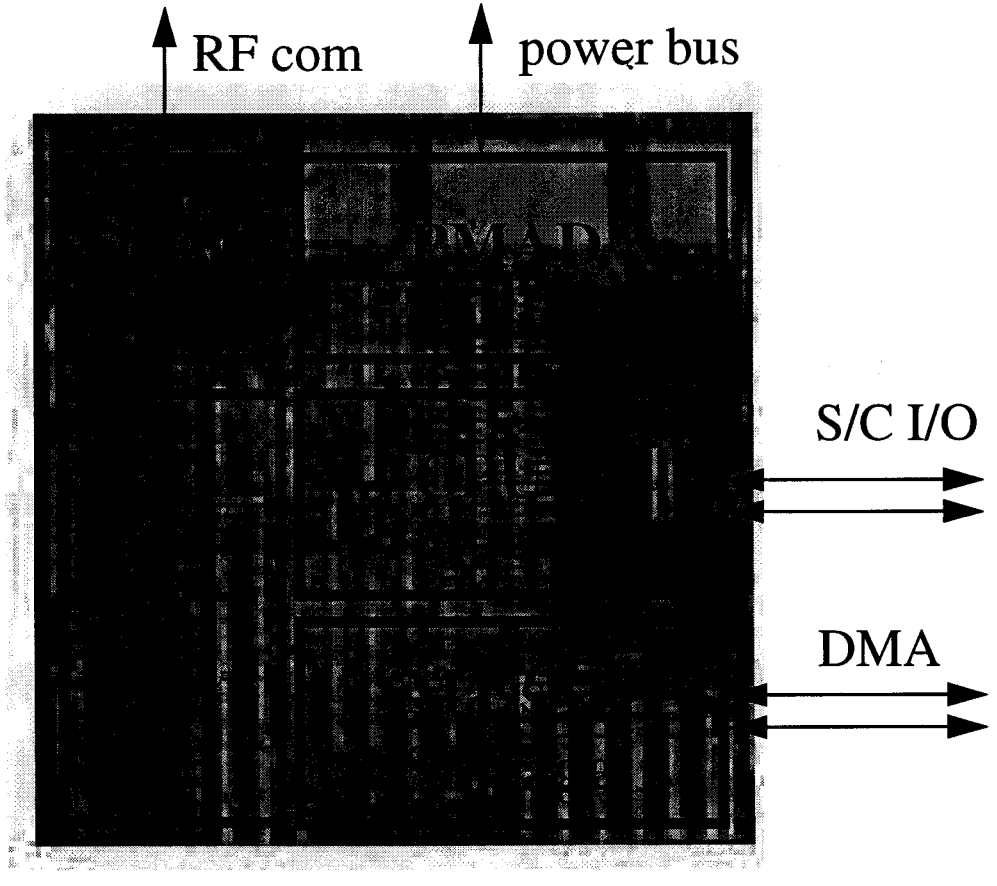


Programmable Macro-Cells on a single chip

Towards an Avionics System on a Chip Challenge

S/C Avionics System on a Chip includes:

- Power Management and Distribution (PMAD),
- Digital Communications,
- Central Processing Unit (CPU),
- Mass Storage: volatile and non-volatile,
- Active Pixel Sensor technology.
- Formal Specification using VHDL
- Automated Design Synthesis for:
  - * different requirements
  - * design for testability
  - * design for reliability
  - * built-in self-test (BIST)
  - * formal verification and test.



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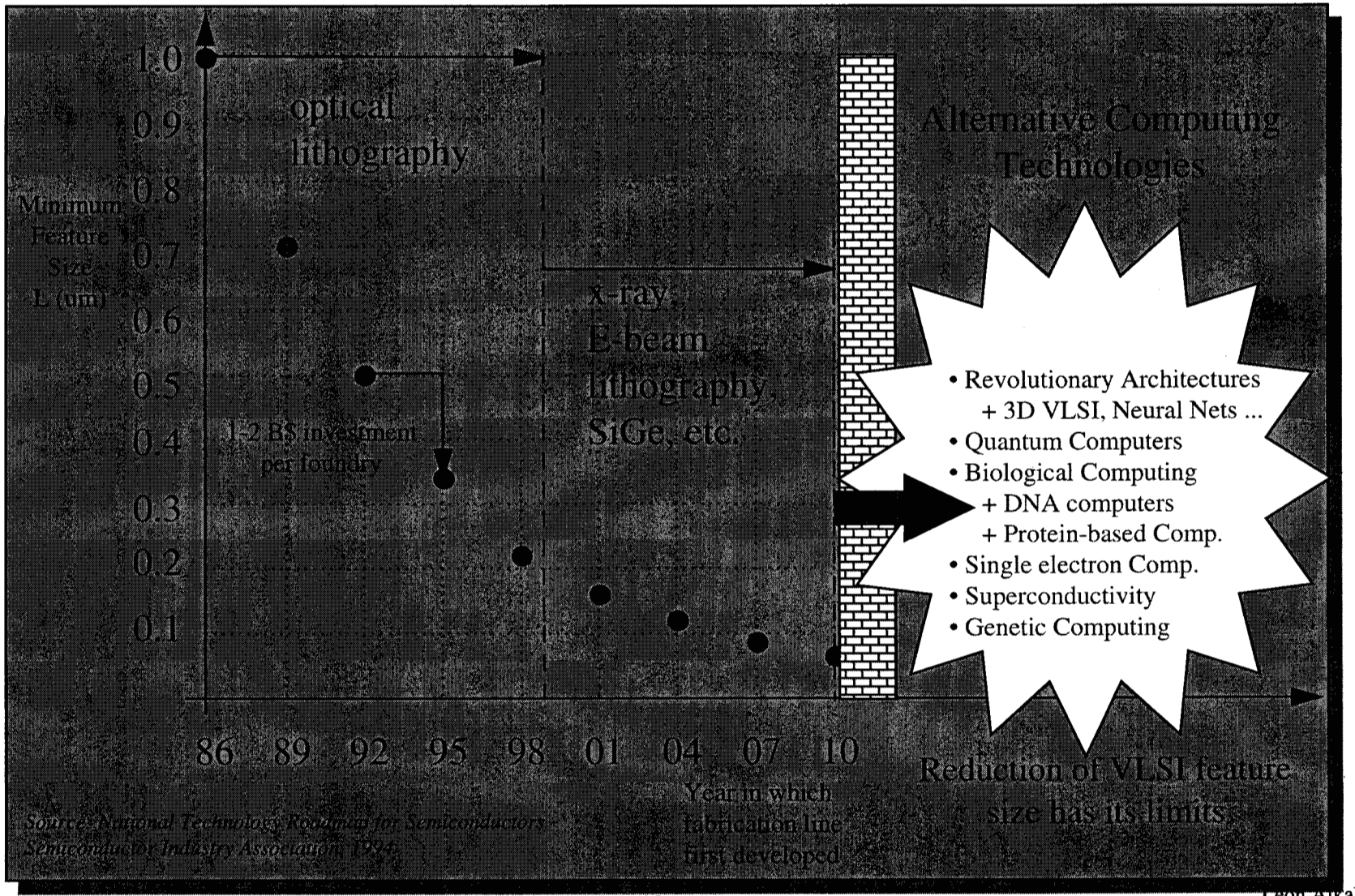
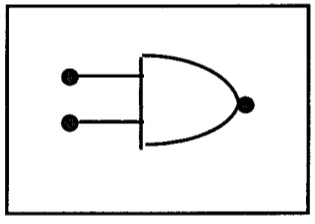
Avionics System on a chip Technology Challenges

- Semiconductor materials such as metalization technologies, and fabrication processes.
- Semiconductor technology (back and front end-of-the-line) research for mixed signal, low-voltage, highly scaled integrated circuits, including high-frequency telecommunications processing, mixed voltage power management and distribution, high-speed digital logic, reprogrammable gate-arrays, volatile and non-volatile storage, integrated sensors and Micro Electro Mechanical Systems (MEMS).
- Microsystems architectures design, specification, and simulation.
- Electrical signal modeling, design and fabrication.
- Design for reliability, high-yield, and physics of failure modeling and simulation.
- Design for structural integrity and thermal management.
- Design for testability and built-in self test.
- Custom VLSI design, standard library development, virtual standard interfaces.
- Evaluation of commercial foundries and industrial partnerships for system on a chip fabrication.

Revolutionary Computing Architectures Challenge



Superconduction Logic



Superconducting gate

WHAT

Low temperature quantization of magnetic flux in superconducting Josephson junctions enables logic elements that consume very low power and operate at picosecond speed.

WHY: 100 times the speed of the fastest silicon gates, 0.001 times the power of silicon gates per logic operation

CHALLENGES: Requires cryogenic temperatures, 4 - 10 K for LTS, 77 - 100 K for HTS refrigeration power negates much of the low power advantaage.

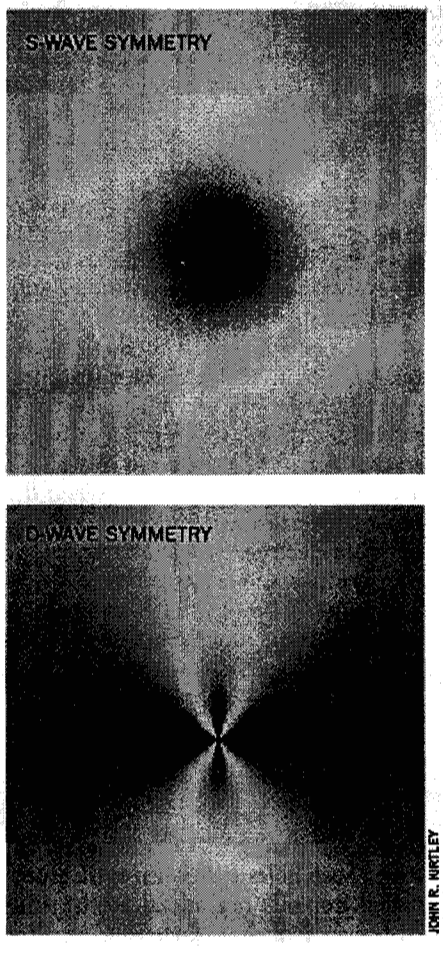
HTS materials are difficult to process and integrate with non SC components

STATUS: 10^4 gates in LTS, 100 gates in HTS

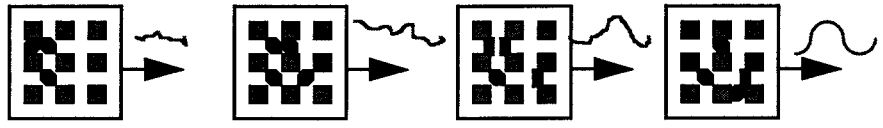
PLAYERS: Hypress, TRW, Westinghouse, several universities

OPPORTUNIT: NASA can play a major role. Direct application to ground supercomputing minimizes refrigeration as a problem.

Applicable to space computing if S/C carrys cryogen, e.g. SIRTF



Evolvable Reconfigurable Hardware



What **Hardware (electronics in particular) that can self-reconfigure under the guidance of an evolutionary algorithm.** E.g. FPGAs configured by Genetic Algorithms.

Why **Self adaptation to new requirements/situations/environments.**

Status **Very new field. Promising results by successful evolution of some simple circuits, digital (directly in hardware-FPGAs) and analog (in software simulations)**

Challenges
- **Huge search space, thus time to evolve may be long**
- **No reconfigurable analog electronics**

Who **No direct research in this field in US, in Japan Electrotechnical Lab gets over $1M**
In US there is research in the "parent" disciplines: Reconfigurable logic (National Semiconductor, Motorola, MIT, UIUC, CMU), and Evolutionary Algorithms applied to circuit evolution (Stanford).

Opportunity

Benefit for space programs: On-board ability to evolve new electronic functionalities which may be needed to satisfy unforeseen conditions that appear during space missions

Potential revolution in computing - NASA can play a major role - JPL can lead

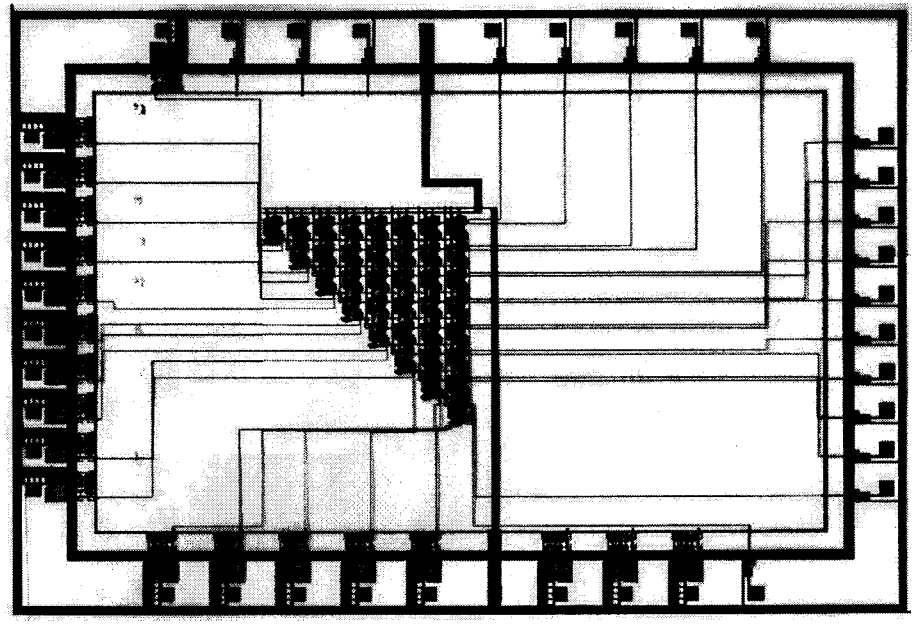
Ultra Low Power Electronics

What 0.9 volt Silicon on Insulator (SOI) microelectronics at 0.18 μ

Why 50-100 x reduction in power

Status MIT/LL funded by DARPA has fabbed worlds first SOI ultra low power technology. NASA plans flight validation experiment.

Challenge: Making it radiation tolerant.

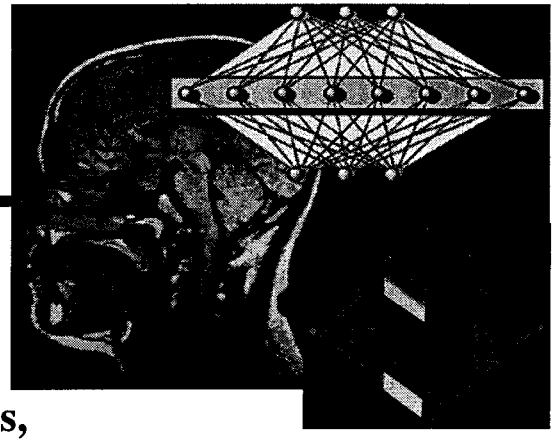


Who: MIT/LL, Sun, HP, Intel, SRC, JPL, etc.

Opportunity: NASA can lead the world in the use of radiation tolerant low power technology that is of use to both Earth based and space based applications.

Potential Revolution: For NASA, use of ULPE could further reduce the dependency on radiation power source.

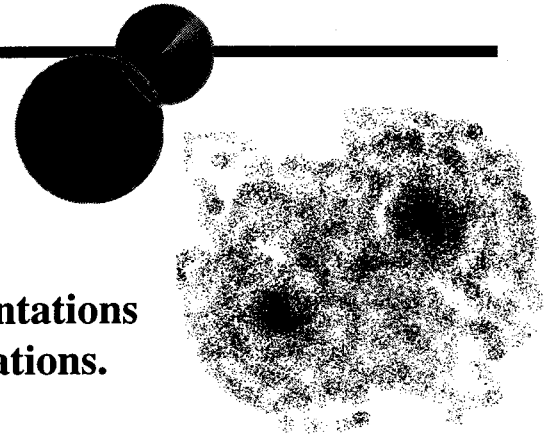
Neural Networks



What	**Biologically inspired parallel distributed processing systems, consisting of highly interconnected simple computational units (neurons).**
Why	**Adaptive signal processing; sensory data/image classification/recognition; unique ability to learn models for prediction, decision-making and control; high speed; robustness.**
Status	**Active research area and several commercial implementations, however, very little of the research targets NASA spacecraft needs.**
Challenges	**Requires more efficient learning algorithms; on-chip learning; self-configuring architectures; efficient interfaces with sensors and other processing elements .**
Who	**Caltech/JPL, Carnegie-Mellon U, Boston U, UCLA, AT&T, IBM, Ford.**
Opportunity	**Brain-like neural computation has high promisses for intelligent information processing. Could enable high levels of autonomy on-board: learning of (and adaptation to) new environments, on-board high speed SAR processing and pattern recognition, on ground - intelligent data minning of large databases.**

<u>Potential revolution in computing - NASA can play a major role</u>

Fuzzy Logic



What Modeling approach based on multivalued ("gray") representations - an extension from bivalued ("black and white") representations.

Why Enables reasoning with imprecise information.

Status Fuzzy control is currently used in commercial applications. More applied research is needed in fuzzy decision-making, and fuzzy optimization.

Challenges Challenges are application specific. For effective insertion of this technology into NASA missions one needs focused research initiatives combined with clear flight demo objectives.

Who Universities - UC Berkeley, SUNY Binghamton, U Missouri
Industry - Lockheed Martin, Rockwell, Motorola, National Semiconductor.

Opportunity

Increased spacecraft autonomy allowing:

- decisions from imprecise information
- qualitative on-board reasoning
- communication with ground in qualitative terms

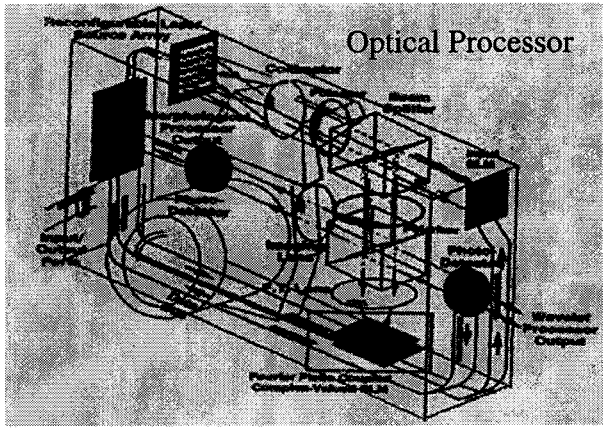
Optical Processing

WHAT

Recent advances in semiconductor lasers, integrated optics, and spatial light modulators, have enabled very high speed parallel optical image processing and pattern recognition with very low power and volume.

WHY: 100 times the speed of a parallel computer (e.g. Cray), 0.01 times the volume/weight and 0.01 times the power consumption for an optical correlation operation.

CHALLENGES: Requires further device and component development to ensure space qualification.



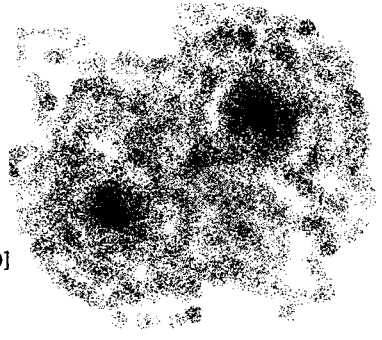
STATUS: A 35 mm camera-size processor with 512 x 512 image frame size, 8 bit grayscale resolution, and 1,000 - 10,000 frames/sec speed is being developed for target recognition and tracking and for landing hazard detection.

PLAYERS: Hughes, Lockheed Martin, Litton, several universities including Caltech, USC, etc.

OPPORTUNITY: NASA microspacecraft landers can benefit from the precision landing, landmark tracking, and hazard avoidance capabilities provided by compact optical processors.

Quantum Computing

What Revolutionary computing technology based on discreet quantum states of electronsin an atom. "Qubits" represent the *superposition* of wavess representing quantum states.



Why Can be used to solve very complex exponential problems in polyno enable non-deterministic computing.

Status Theory is well understood and based on quantum mechanics. Preliminary lab demos reported recently in 1996.

Challenge: To make quantum gates, define quantum algebra, and computational model. Main problem is data R/W and setting initial conditions.

Who: CIT, Oak Ridge NL, Los Alamos NL.

Opportunity: Future autonomous spacecraft.

Potential Revolution: Solving complex problems such as science/knowledge discovery and data mining.

Genetic Programming and Computation

WHAT: New class of computational methods based on biological evolutionary principles solves large complex optimization problems.

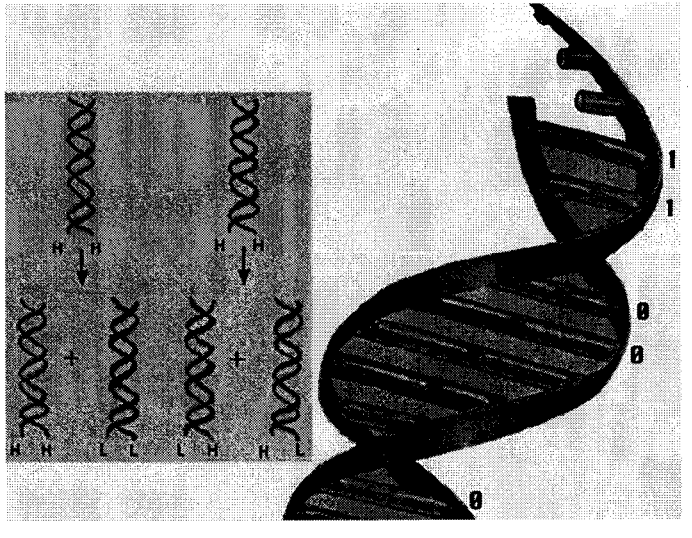
WHY: Provides robust adaptive search technique to solve important optimization problems for reducing cost and optimizing performance in many engineering and artificially intelligent systems.

CHALLENGES: Method is relatively new and more complete theory is desired.

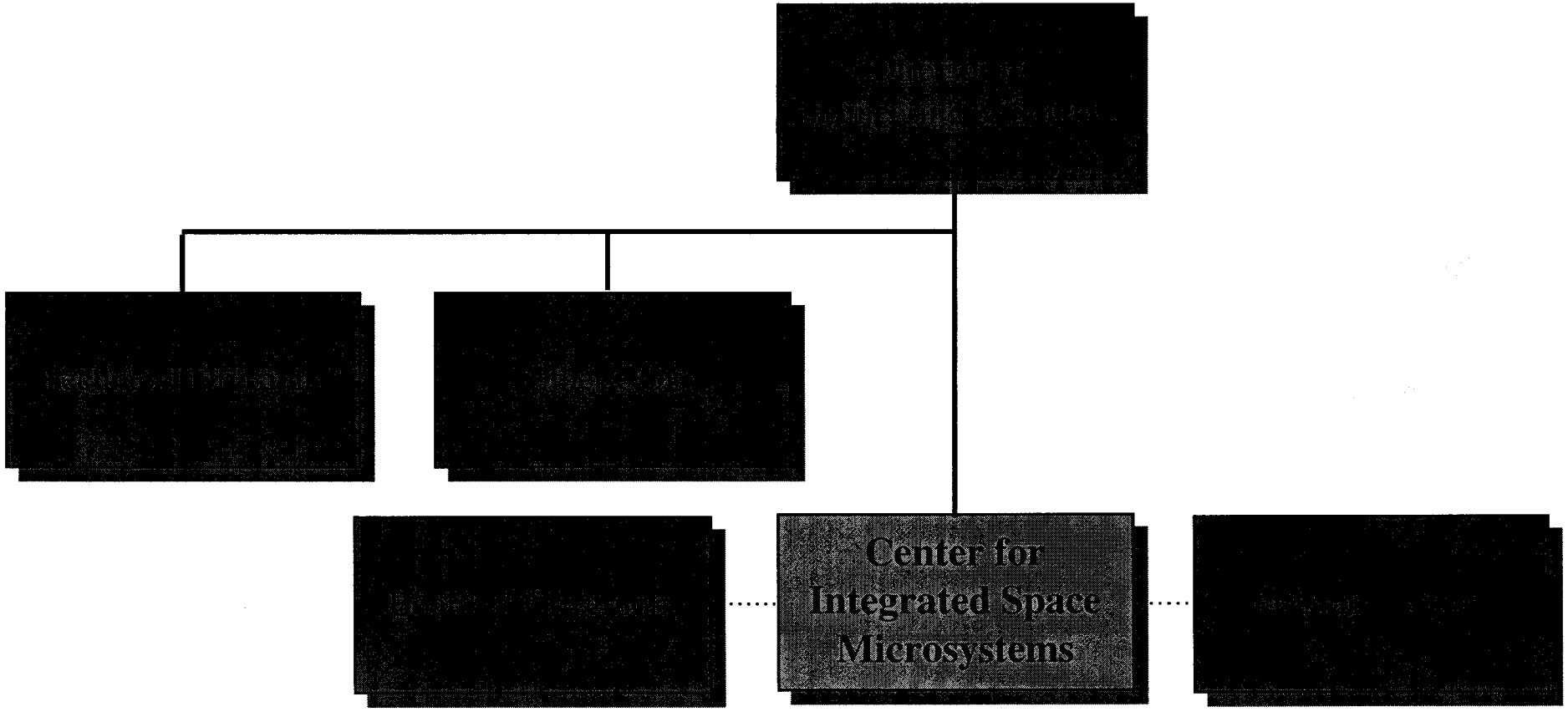
STATUS: Routine optimization in 1000-plus unknown variables.

PLAYERS: University of Michigan, Ann Arbor,
University of California, San Diego (GAUCSD package),
NASA Johnson Space Flight Center (SPLICER package),
European Community GA project (GAME package),
University College, London (GAGA package)
German National Research Center for Computer Science (PEGASUS package),

OPPORTUNITIES: JPL MDL facility - Design of special purpose GA hardware. Increased S/C autonomy, on-board planning, scheduling and resource allocation. Minimizes S/C reliance on ground support and operations.



CISM Organizational Placement as a JPL Center of Excellence (COE)



Summary

- CISM recognized as NASA/JPL Center of Excellence
- CISM Office and laboratory location found; initial occupation begun
- CISM Laboratory modifications in process
- Close ties to X2000 and Advanced Spacecraft Technology Development Program established
- CISM organization, key positions, & functional areas being planned
- In process of developing detailed CISM plan starting FY 98 for all three elements: X2000 avionics (near-term); avionics system on a chip (long-term); quantum electronics (far-term);
- Major shortfall is in FY 97 to start-up CISM at full speed in FY 98.